CV-86-08

Ontario

Ministry of
Transportation and
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Technology and
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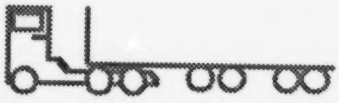
Demonstration of Tractor-Trailer Performance: 5-Axle 48 ft Semi



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CV-86-08

Demonstration of Tractor-Trailer Performance: 5-Axle 48 ft Semi

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Prepared for:
CCMTA/RTAC Vehicle Weights and Dimensions Study

Published by:
Automotive Technology and Systems Office
Transportation Technology and Energy Branch
Ontario Ministry of Transportation and Communications
Hon. Ed Fulton, Minister
D.G. Hobbs, Deputy Minister

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Ontario Ministry of Transportation and Communications
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

June 1986

Technical Report Documentation Page

MTC Report Number CV-86-08	ISBN Number:	Other Document Number:	Date: June 1986
Title: Demonstration of Baseline Vehicle Performance: 5-Axle 48 ft Semitrailer			
Authors (name, title and/or organization): J.R. Billing, Head, Commercial Vehicles Section W. Mercer, Research Engineer			
Published by: Automotive Technology and Systems Office, Transportation Technology and Energy Branch, MTC		**Client Group:** CCMTA/RTAC Vehicle Weights and Dimensions Study	
Participating Agencies:			

Abstract:
A 5-axle 48 ft (14.63 m) semitrailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated an additional vehicle by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

Key Words: truck testing, offtracking, truck turning, air brake system, braking, truck dynamic tests, rearward amplification, rollover, lane change, tilt test

Comments:

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ABSTRACT

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ACKNOWLEDGEMENTS

This work was conducted on behalf of the CCMTA/RTAC Vehicle Weights and Dimensions Study, managed by J.R. Pearson. The trailer was provided by the Roads and Transportation Association of Canada (RTAC). Facilities of the Transport Canada Motor Vehicle Test Centre were made available to the Ministry of Transportation and Communications (MTC). Assistance with vehicle preparation, delivery, and refurbishment was arranged by Mr. Pearson in support of this work.

The work was principally undertaken by the staff of the Automotive Technology and Systems Office of the Transportation Technology and Energy Branch of MTC: N.R. Carlton; G.B. Giles; C.P. Lam, P.Eng.; W.R. Stephenson, P.Eng.; and M.E. Wolkowicz; and assigned students G. Goertzen, S. Jazic, and D.R. Sykes. Assistance was provided by staff of various other departments of the ministry and other organizations.

The efforts of all involved are hereby acknowledged with gratitude.

1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle configuration for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of a 5-axle 48 ft (14.63 m) semitrailer combination, which is one of the additional vehicles. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and single 48 ft (14.63 m) tandem flatbed-type trailer. The combination is typical of equipment used in Central Canada, where additional weight can be carried on a widespread tandem axle. The same combination was also tested concurrently as a 6- and 7-axle vehicle [8,9].

The equipment for these tests was provided by the Roads and Transportation Association of Canada (RTAC). No modifications were made to the trailer except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected.

The trailer was manufactured by Fruehauf and was a 48 ft (14.63 m) flatbed semitrailer with two fixed axles and two airlift axles that were raised for these tests. The trailer was manufactured in July 1984, bore the serial number 2H8P04843ER033601, and was model PBX4W 48102.

The trailer had a nominal length of 14.63 m (48 ft) and a nominal width of 2.59 m (102 in). The trailer suspension comprised a Reyco four-spring leaf system with long equalizer arms on the fixed axles, which had a spacing of 2.77 m (109 in). The spring centre width was 0.96 m (38 in), and the track width was 2.44 m (96 in). The vehicle overall length was 18.69 m (61.32 ft). The trailer was rated at 9620 kg/axle (21 164 lb/axle). The ffixed ftandem axle was placed to the rear of the trailer, because in that position it can accrue a greater gross weight as a 4-axle trailer. However, current 48 ft (4.63 m) semi-trailers often have their axles forward, at the same distance from the trailer kingpin as for a 45 ft (13.72 m) semi-trailer, because under current regulations no additional gross weight is gained for a rearward placement of the axles, and the turning performance is improved.

The trailer was fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 160 km (100 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 22 595 kg (49 710 lb). Concrete blocks were used to obtain a loaded weight of 34 409 kg (75 680 lb). Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	4 918	10 820	5 055	11 120
2	5 368	11 810	7 336	16 120
3	4 686	10 310	6 827	15 020
4	4 082	8 980	7 618	16 760
5	3 541	7 790	7 573	16 660
Total	22 595	49 710	34 409	75 680

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment, because of the two lifted axles on the trailer, and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was nearly attained, with the exception of the tractor drive axles. The legal gross weight for the vehicle tested varies between 36 500 and about 44 000 kg (80 300 to 96 800 lb), depending upon the province.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.33 m (13 in) below the top of the floor. The centre of gravity height was estimated as 0.09 m (3.5 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger and safety cable attachments and load block retention sills were installed on the trailer.
3/ Outriggers were installed on the trailer.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer bed to achieve specified axle loads.
8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailer.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Tires were run a nominal distance of 160 km (100 mi).
14/ Articulation angle between the tractor and trailer was calibrated.
15/ Photographs and video film were taken to record details of the vehicle and test equipment.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailer for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the trailer were mounted in a box placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition, or runs were made to evaluate the ability of the vehicle to make a particular manoeuvre.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyro package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyro package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	19.792°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyro	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Dolly 1 hitch angle	Spectrol 139 potentiometer	25.0°
19	Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
21	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown in Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values shown in the last column of Table 3 is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4. After averaging for both directions and correcting for differences in axle track width, the offtracking of 2.41 m (7.9 ft), shown in Figure 4, became 2.82 m (9.25 ft).

Table 3/ Offtracking

Axle No.	Track Width (m)	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.52	27.59	0.07	27.55	27.56	+0.04
2	2.37	27.22	27.37	0.15	27.30	27.21	-0.31
3	2.37	27.21	27.37	0.16	27.29	27.21	-0.29
4	2.37	24.74	24.79	0.05	24.77	24.77	0.00
5	2.37	24.68	24.68	0.0	24.68	24.77	+0.36

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft) radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn, at a point close to its maximum excursion out of the exit lane. The maximum excursion out of lane was 2.00 m (6.56 ft), over one-half a lane width. It was out of the exit lane for a distance of 26.0 m (85.3 ft), as derived from Figure 5. This test was conducted at a creep speed and represents about the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was only 0.73 m (2.39 ft) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. The vehicle was driven with the left front wheel tracking the curb. In practice, a driver would allow some clearance on his side, if only to stay clear of catch basins. This would mean the rear axle would come close to the inner curb.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi).

The SAE J982a style test was performed, and the results, presented in Table 4, are the average of several tests, each with a time resolution of 0.02 s. The application and release times of this test are typical of those obtained from tests conducted on other similar combinations. A typical time history response of application and release is presented in

Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.04	0.18	91.9
Axle 2	0.36	0.56	90.4
Axle 5	0.39	0.84	88.1

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1].

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The brake application of about 242 kPa (35 psi) caused all braked wheels to lock, and the tractor jackknifed slightly to the left. No higher brake pressures were used as all axles were already locking at lower pressures. A higher speed would have resulted in a faster jackknife, but use of the tractor front axle brakes would probably have eliminated the jackknife.

A summary of peak vehicle responses is shown in Figure 12, as a function of average treadle valve pressure. The limit of surface adhesion of about 0.15 g was reached at a brake pressure of about 159 kPa (23 psi), when most wheels were locking. The vehicle did not become unstable until a considerably higher brake pressure.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. The test used gates of 22.5 m (73.8 ft) for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. The runs were made in accordance with the standard test procedure [1].

The vehicle combination was evaluated primarily in terms of the lateral acceleration and yaw responses of the vehicle units. These are shown in Figure 13. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration amplitude for both vehicle units tended to rise up to approximately 54 km/h and then stabilized. Heading angle for the tractor tended to decrease as speed increased, whereas heading angle of the trailer remained relatively uniform. Data indicated that the tractor slid at the higher speeds, while tractor heading angle decreased. The driver commented that the tractor tires clattered and howled, indicating operation at or near their performance limits. A typical run at 60 km/h is shown in Figure 14.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63, 84, and 94 km/h, with steer input periods between about 2 and 5 s.

The vehicle combination was evaluated in terms of the lateral acceleration responses of the vehicle units. Rearward amplification of lateral acceleration of the trailer is presented in Figure 15, as a function of tractor steer input period for the three test speeds. This is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 15, that rearward amplification increases only slightly with speed for this vehicle. It is also somewhat sensitive to steer period, reaching the highest value of about 0.90 at around 3.5 s.

The results, show that, at highway speed, this is a very stable vehicle, because of its low response to input. Figure 16 shows the response of a typical run for a steer period of about 2 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a lane-change manoeuvre, considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

The test used a gate of 30 m (98.4 ft) for the lane change. This was used to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with that described in the preceding sections

The results from all runs are summarized in Figure 17. The peak-to-peak lateral acceleration, roll, and yaw (or heading) angles all remained relatively uniform throughout the speed range. Lateral acceleration and roll gains are also shown in Figure 17. The lateral acceleration gain is consistent with rearward amplification found throughout the speed range.

Overall, this vehicle appeared to be quite stable with no major trends throughout its speed range. The consistent yaw overshoot, seen in Figure 17, appears to be due to tractor steer correcting in the exit lane and moderate tire slippage. It did not appear to increase with speed until modest trailer swing occurred at the limiting speed of 94 km/h.

Figure 18 shows a typical time history of a run at 94 km/h.

4.9/ Normal Straight-Line Driving

The objective of this test was to attempt to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was very stable, and if any slight steer corrections made in the course of normal driving, and roughness of

the test track surface, resulted in trailer sway, it was not readily perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 0.92 g/° of RMS steer input.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The results of this test are summarized in Figure 19. The vehicle combination was evaluated primarily in terms of the roll response of the vehicle units. Average steady-state roll angle is presented in Figure 19 as a function of tractor lateral acceleration. Average steady-state articulation angle is also shown in Figure 19. This decreases modestly with increase in lateral acceleration, and as a consequence, the offtracking decreases. The lateral force experienced by the tractor fifth wheel is also shown in Figure 19, as a function of tractor lateral acceleration. This shows a gradient of 52.5 kN/g (11 800 lb/g).

At the limiting speed of 63 km/h, a lateral acceleration of 0.52 g, the outrigger touched down and the trailer swung out, as shown in Figures 20 and 21. The driver then steered out of the circle. It is possible the vehicle would not have rolled over.

A tilt test was conducted on this vehicle as part of a separate test program [13]. The vehicle is shown on the tilt table, in Figure 22. The high-side wheels of the rear trailer lifted at a tilt angle of 31.0°, after all corrections were made, which corresponds to a lateral acclera-tion of 0.60 g. This is in quite good agreement with the rear trailer's lateral acceleration at outrigger touchdown of 0.52 g. A full discussion of the tilt test is presented elsewhere [13].

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted. The outrigger assembly and the two airlift axles were was additional to normal trailer equipment, and the characteristics of the trailers were, therefore, somewhat atypical, at least in the empty condition.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. It braked well and was easy to manoeuvre. Its length simply meant it required space to manoeuvre. It exhibited high stability in all manoeuvres.

6/ CONCLUSIONS

An 5-axle tractor semitrailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The trailer was 14.65 m (48 ft) long, and had a 2.77 m (109 m) widespread tandem axle. The vehicle was designated as of particular interest by the study.

The vehic'e was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The length of this vehicle clearly contributed to the significant space required to make turns.

The air brake system was relatively fast and well balanced.

The lateral/directional stability of the vehicle was excellent, both empty on a low-friction surface and loaded on a high-friction surface. The roll stability was high, primarily because of the low trailer centre of gravity height. A higher centre of gravity would have significantly reduced the roll threshold.

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[6] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: A-Train Triple," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-06, June 1986.

[7] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: C-Train Triple," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-07, June 1986.

[8] Billing, J.R., and Mercer, W., "Demonstration of Tractor-Trailer Performance: 6-Axle 48 ft Semi," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-09, June 1986.

[9] Billing, J.R., and Mercer, W., "Demonstration of Tractor-Trailer Performance: 7-Axle 48 ft Semi," Ontario Ministry of Transportation and Communications,Transportation Technology and Energy Branch, Report CV-86-10, June 1986.

[10] Billing, J.R., "Summary of Tests of Baseline Vehicle Performance," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-12, June 1986.

[11] Lam, C.P., and Billing, J.R., "Comparison of Simulation and Test of Baseline and Tractor-Trailer Vehicles," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-11, June 1986.

[12] Heald, K., "Use of the WHI Offtracking Formula," Paper Presented at Transportation Research Board Symposium of Geometric Design for Large Trucks, Denver, Colorado, August 1985.

[13] Delisle, G., "Investigating Articulated Vehicle Roll Stability Using a Tilt Table," Centre de Recherche Industrielle du Quebec, Report No. 645-19168, June 1986.

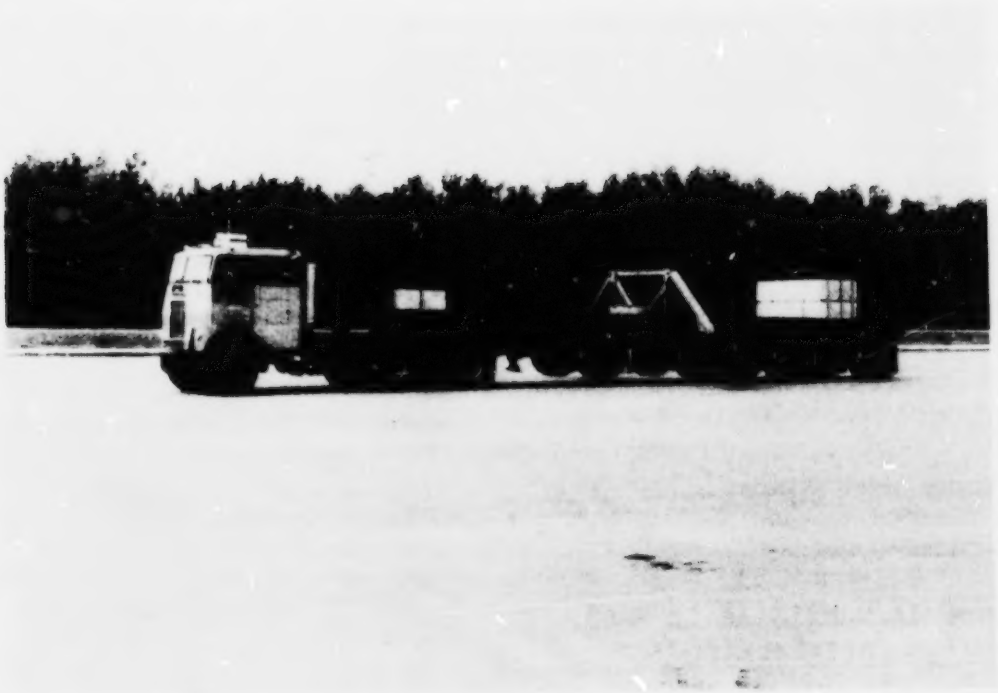


Figure 1/ 5-Axle 48 ft Semi, View of Vehicle

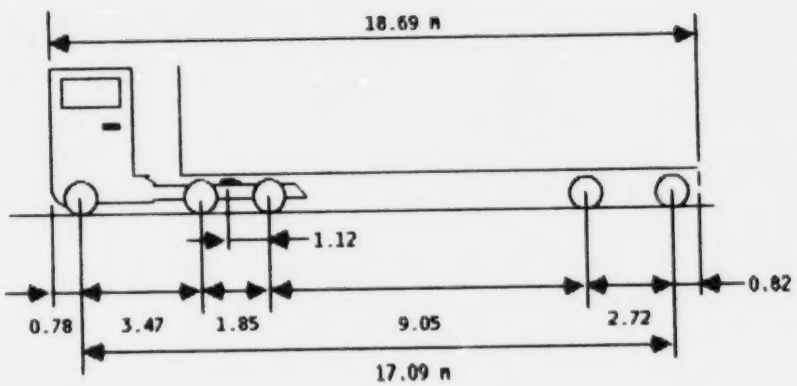


Figure 2/ 5-Axle 48 ft Semi, Vehicle Dimensions

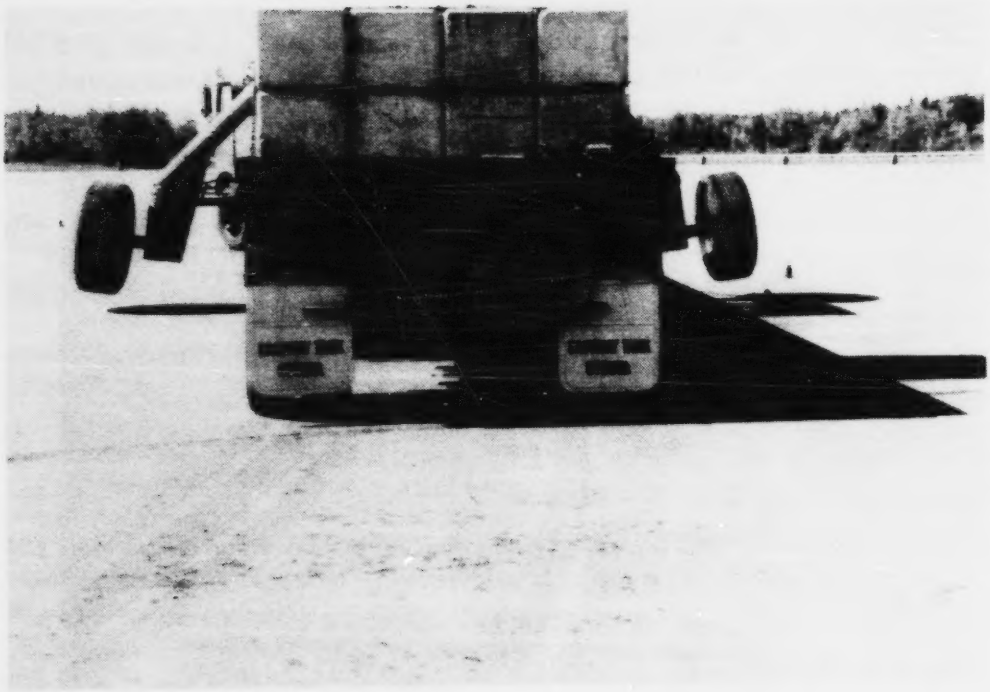


Figure 3/ 5-Axle 48 ft Semi,
Offtracking

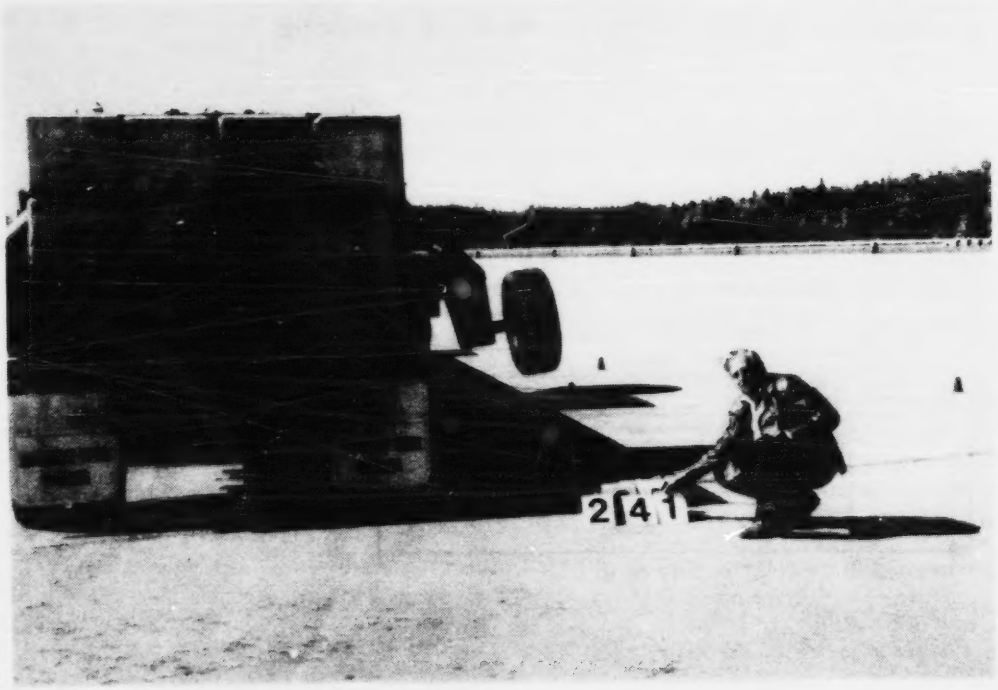
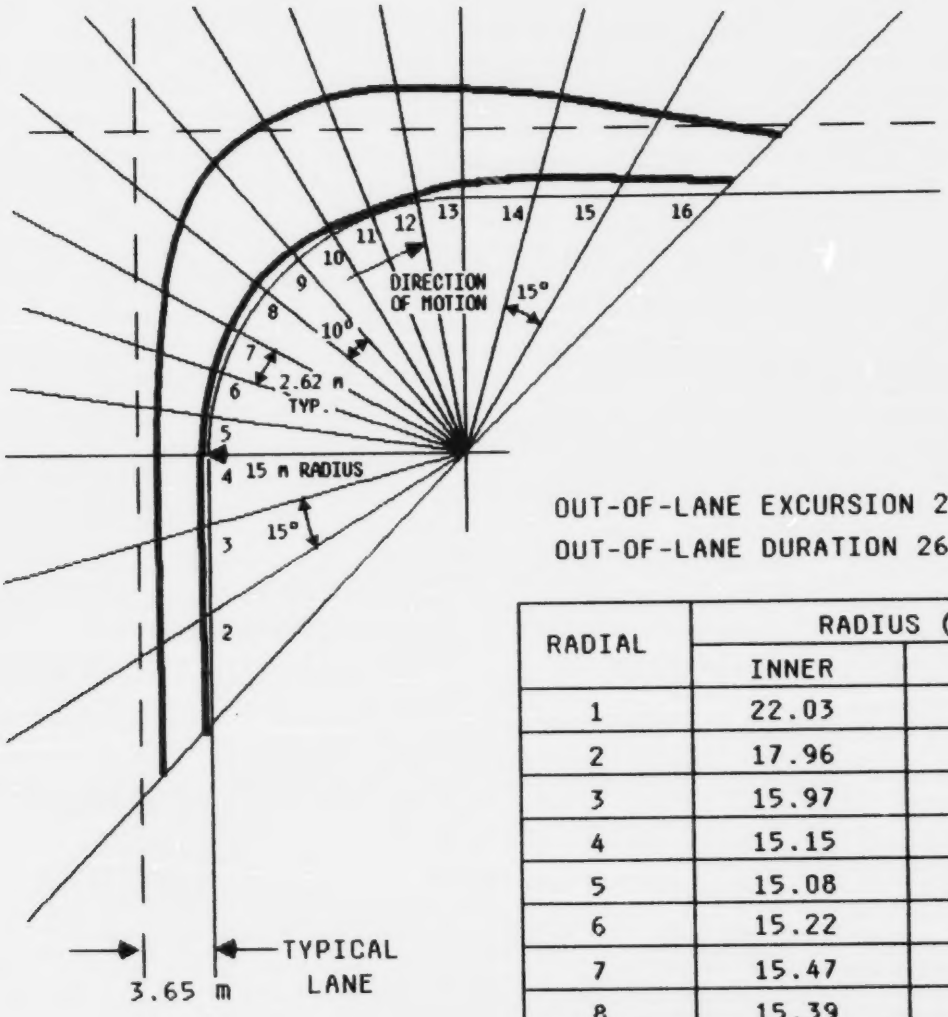


Figure 4/ 5-Axle 48 ft Semi,
Counter-Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 2.0 m

OUT-OF-LANE DURATION 26 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	22.03	-
2	17.96	-
3	15.97	-
4	15.15	17.79
5	15.08	17.90
6	15.22	18.55
7	15.47	19.66
8	15.39	20.88
9	15.18	21.95
10	15.06	22.16
11	15.02	21.87
12	15.12	21.38
13	15.45	20.83
14	16.39	21.27
15	18.33	22.55
16	22.30	25.92

Figure 5/ 5-Axle 48 ft Semi, Right-Hand Turn Swept Path

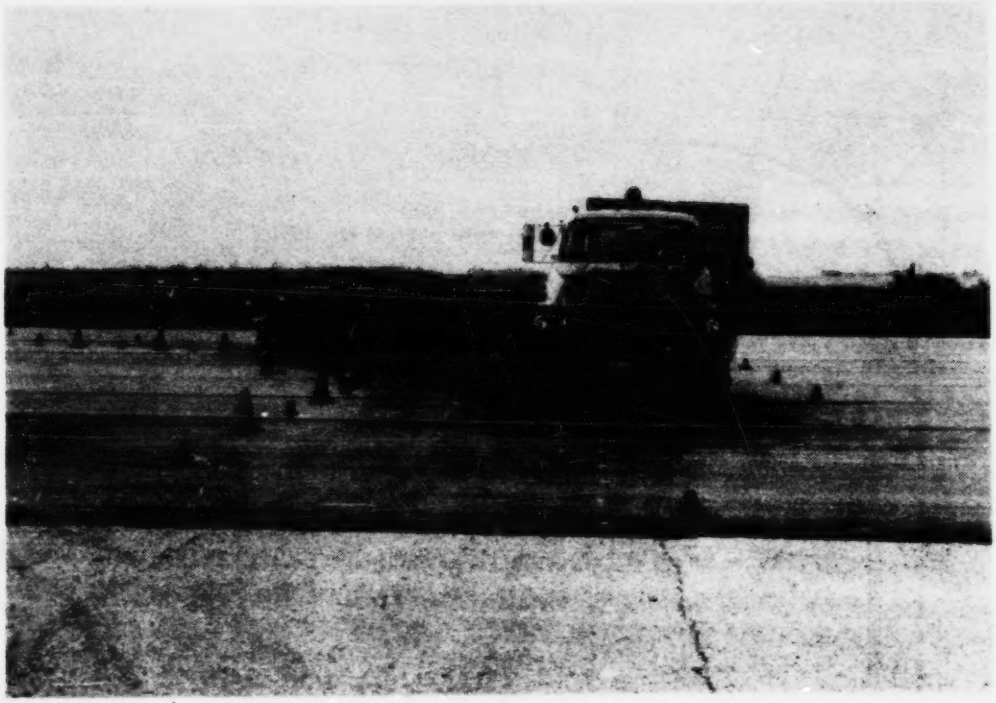


Figure 6/ 5-Axle 48 ft Semi, Right-Hand Turn

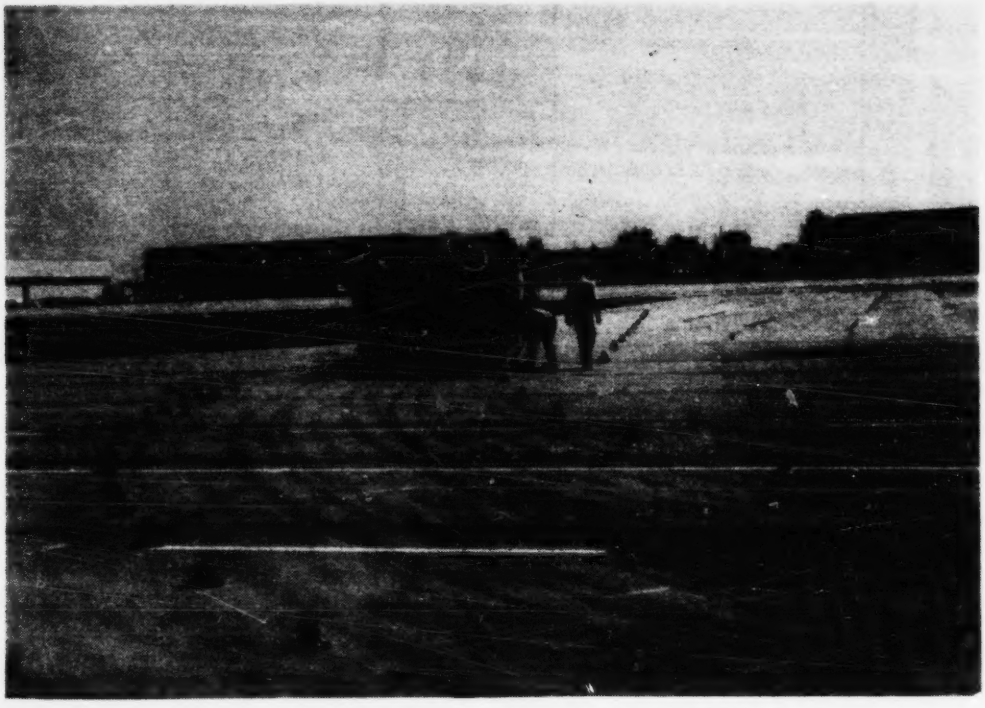
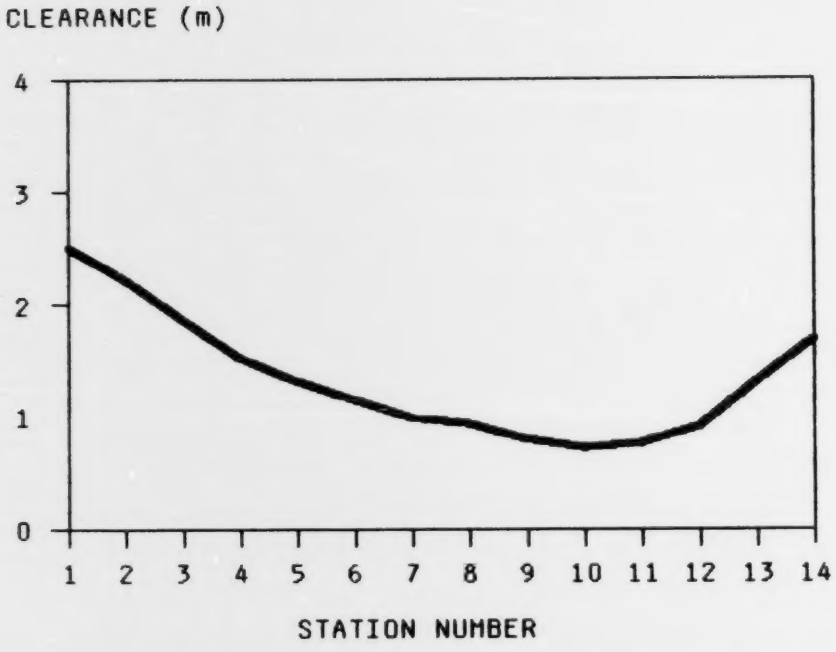


Figure 7/ 5-Axle 48 ft Semi, Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.51
2	2.22
3	1.86
4	1.52
5	1.31
6	1.14
7	0.99
8	0.93
9	0.80
10	0.73 *(LOW)
11	0.76
12	0.92
13	1.31
14	1.70

Figure 8/ 5-Axle 48 ft Semi,
Channelized Right-Turn
Clearance from Inner Curb

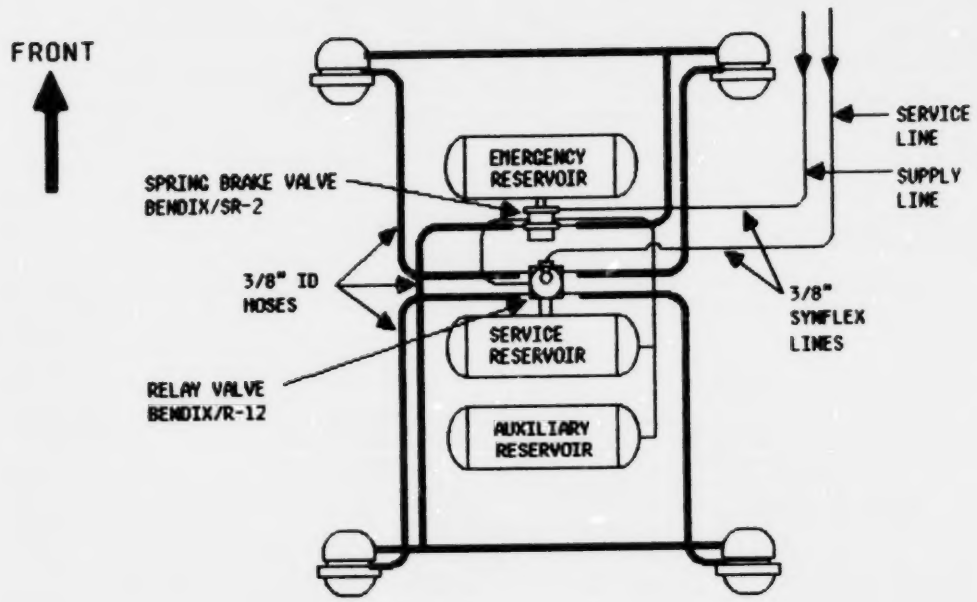


Figure 9/ 5-Axle 48 ft Semi,
Air Brake System Schematic

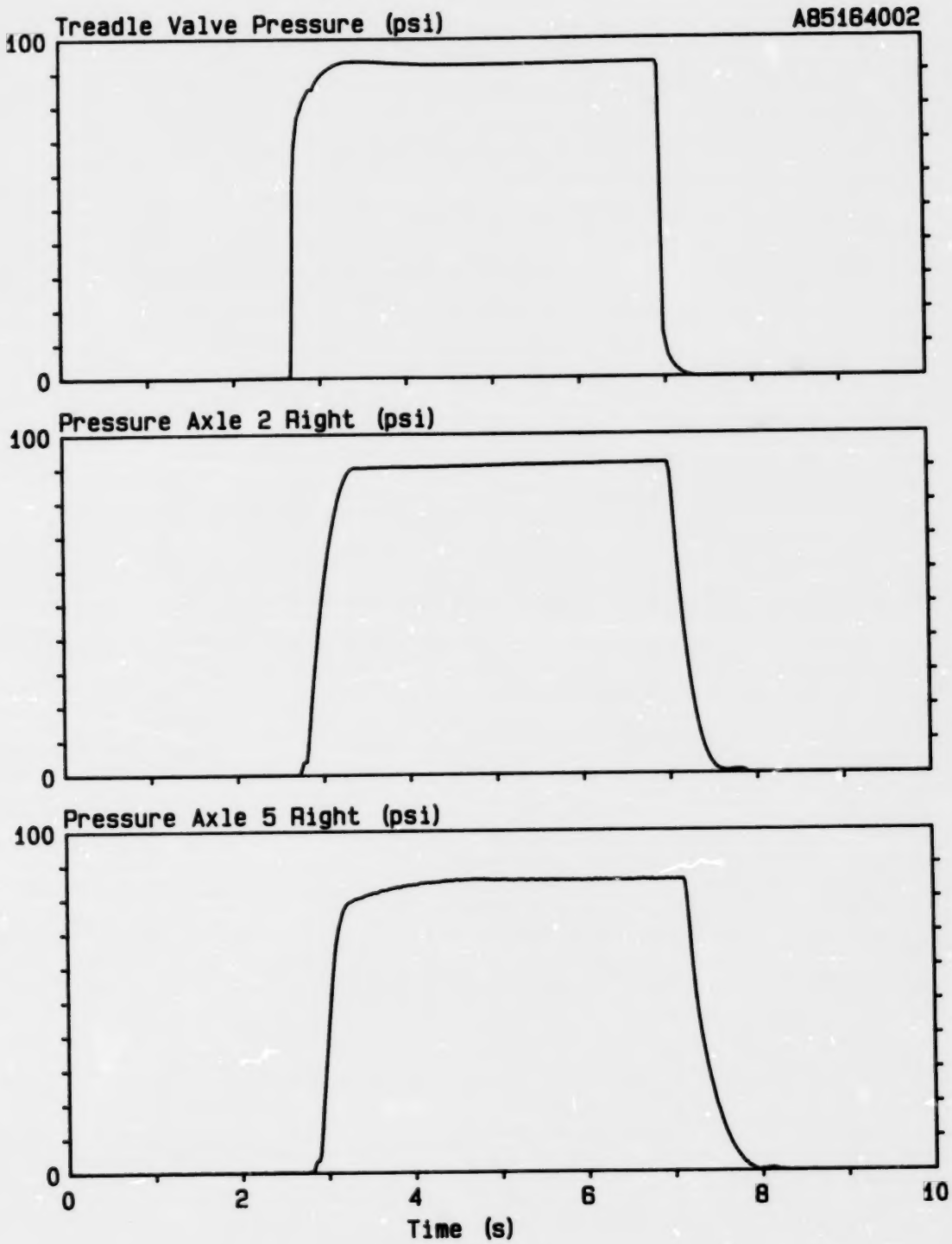


Figure 10/ 5-Axle 48 ft Semi,
Air Brake Application and Release

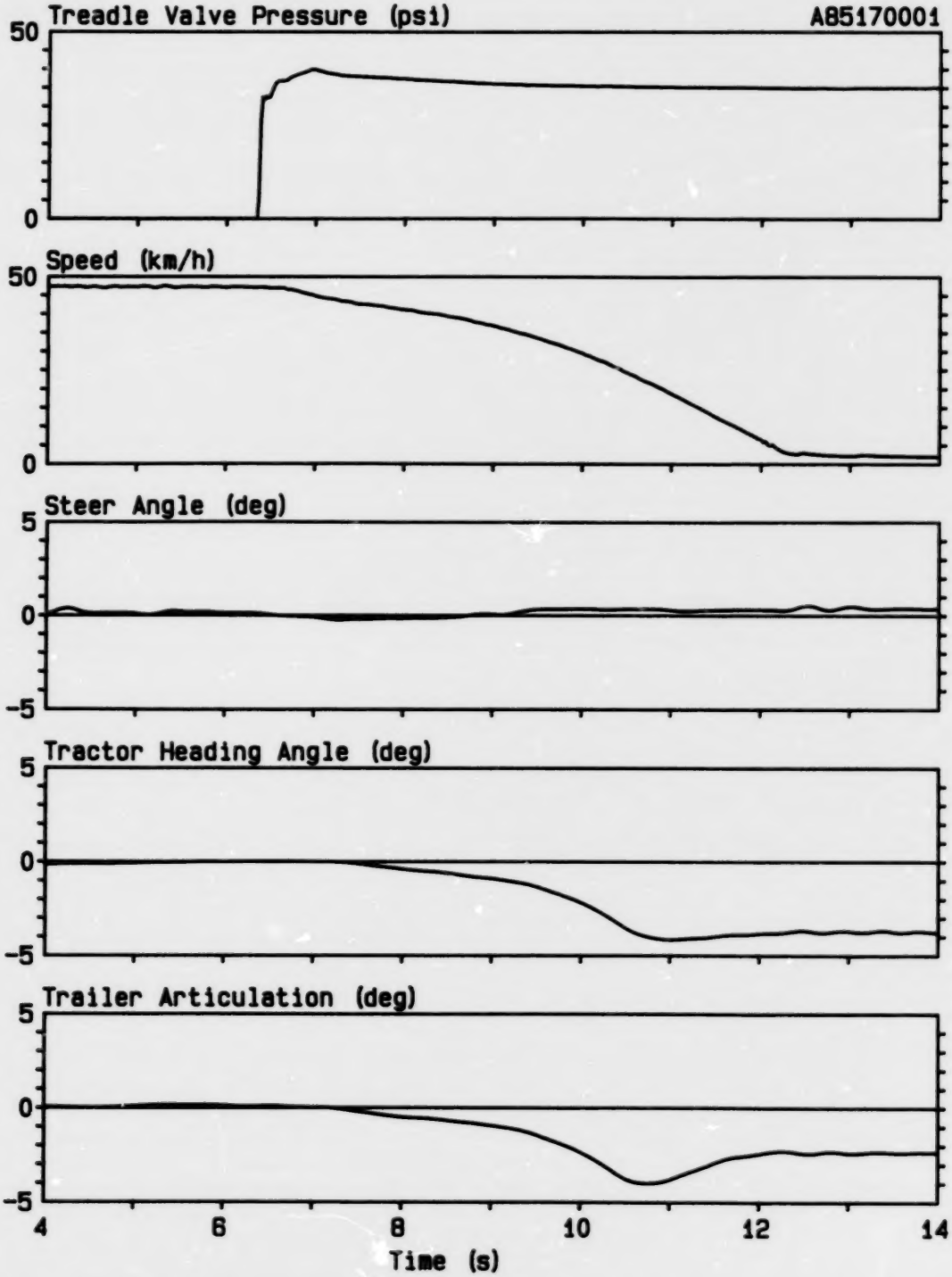


Figure 11/ 5-Axle 48 ft Semi,

Vehicle Response to Straight-Line Braking

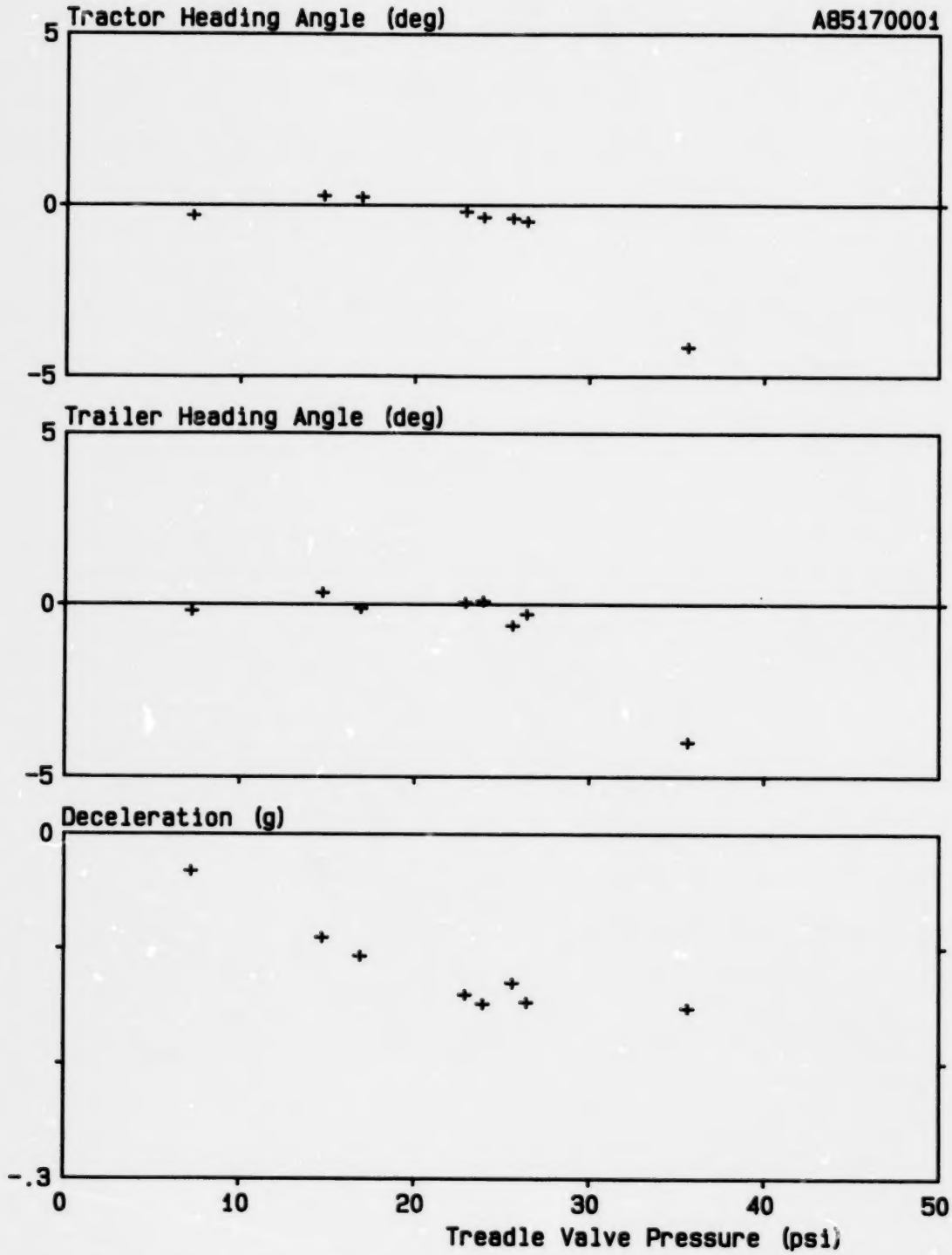


Figure 12/ 5-Axle 48 ft Semi, Straight-Line Braking Responses vs Treadle Valve Pressure

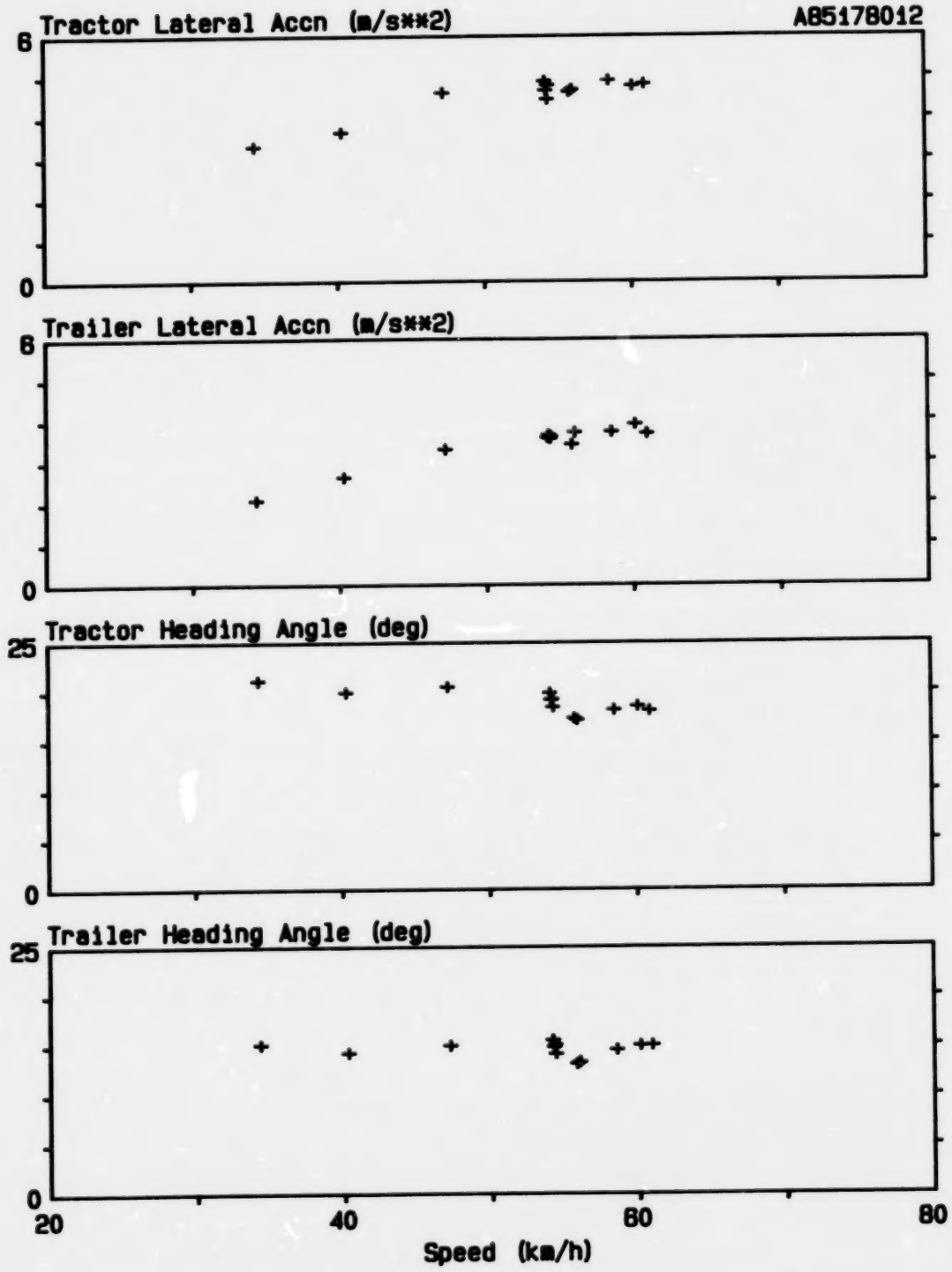


Figure 13/ 5-Axle 48 ft Semi. Evasive Manoeuvre, Peak-to-Peak Responses vs Speed

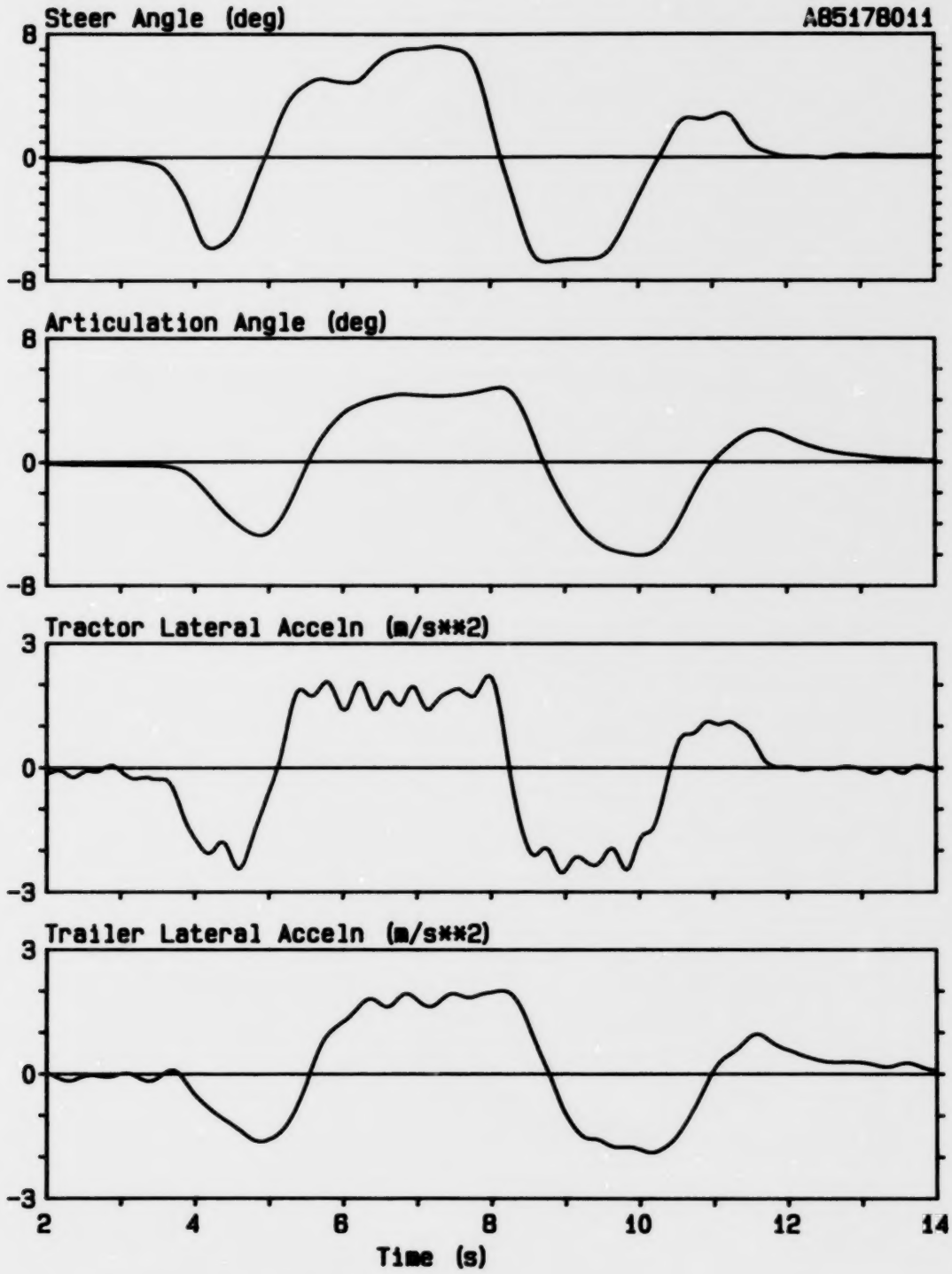


Figure 14/ 5-Axle 48 ft Semi,

Vehicle Response in Evasive Manoeuvre

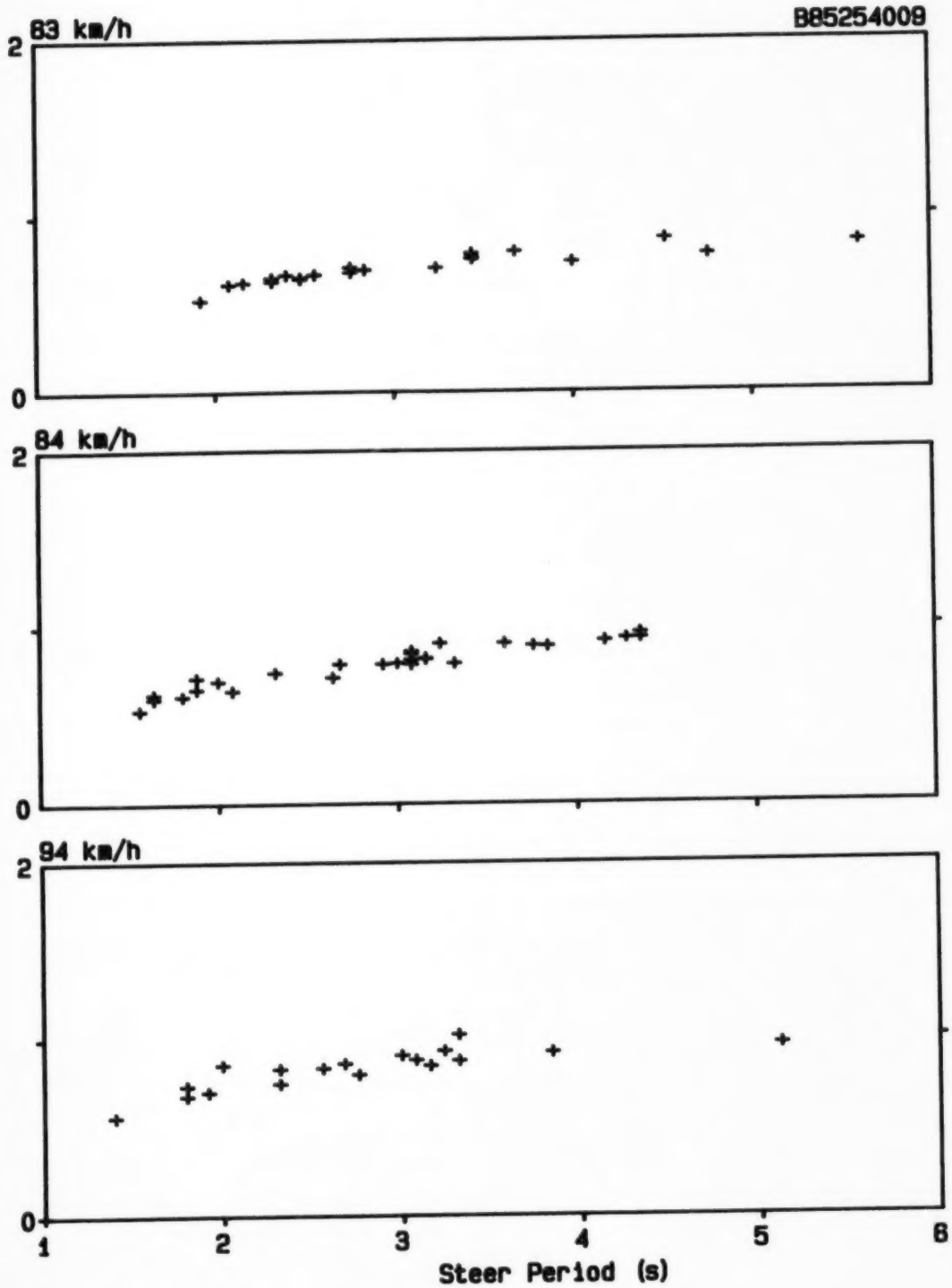


Figure 15/ 5-Axle 48 ft Semi.

Rearward Amplification of Lateral Acceleration

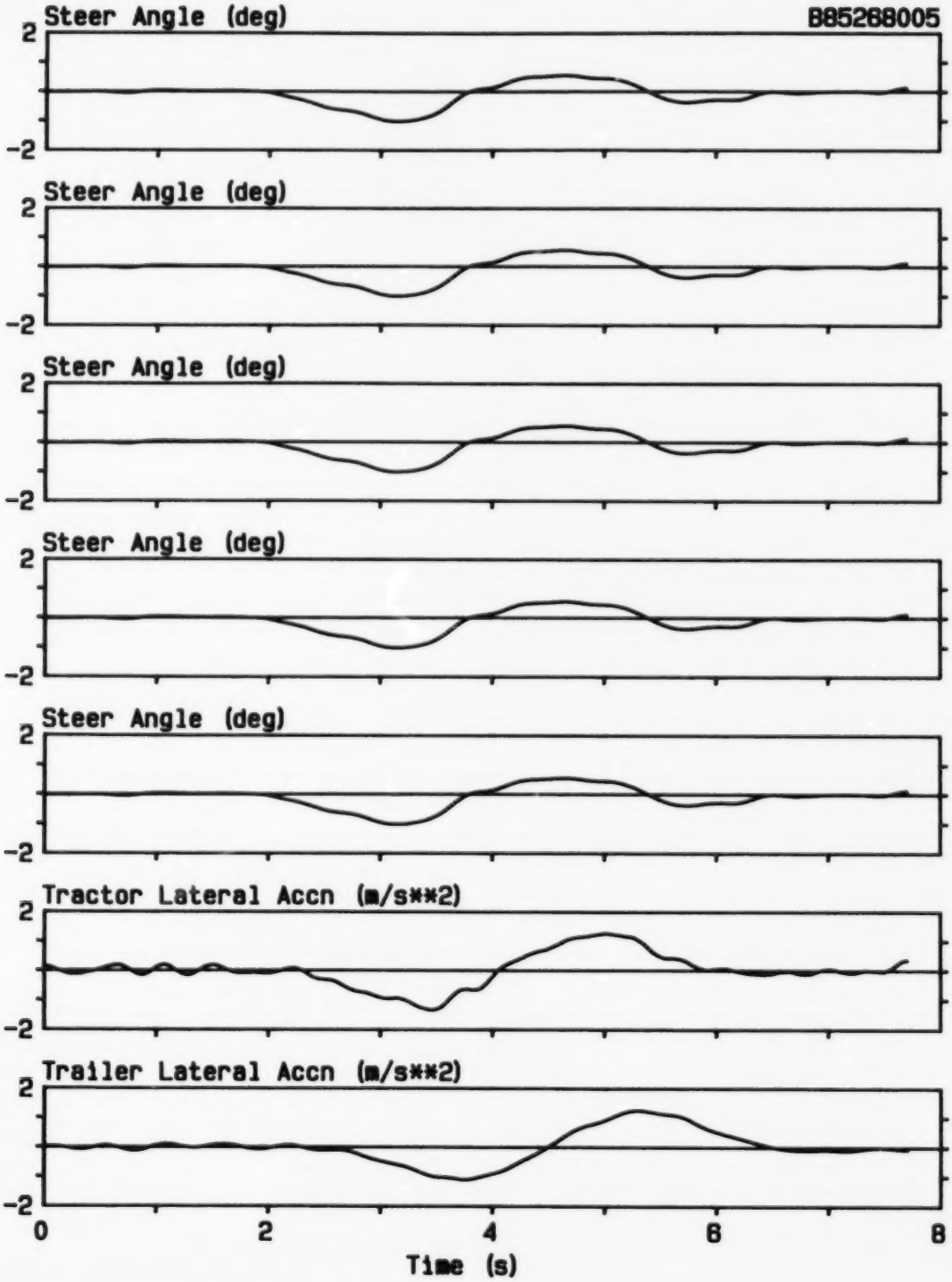


Figure 16/ 5-Axle 48 ft Semi,

Vehicle Response to Sinusoidal Steer at 94 km/h

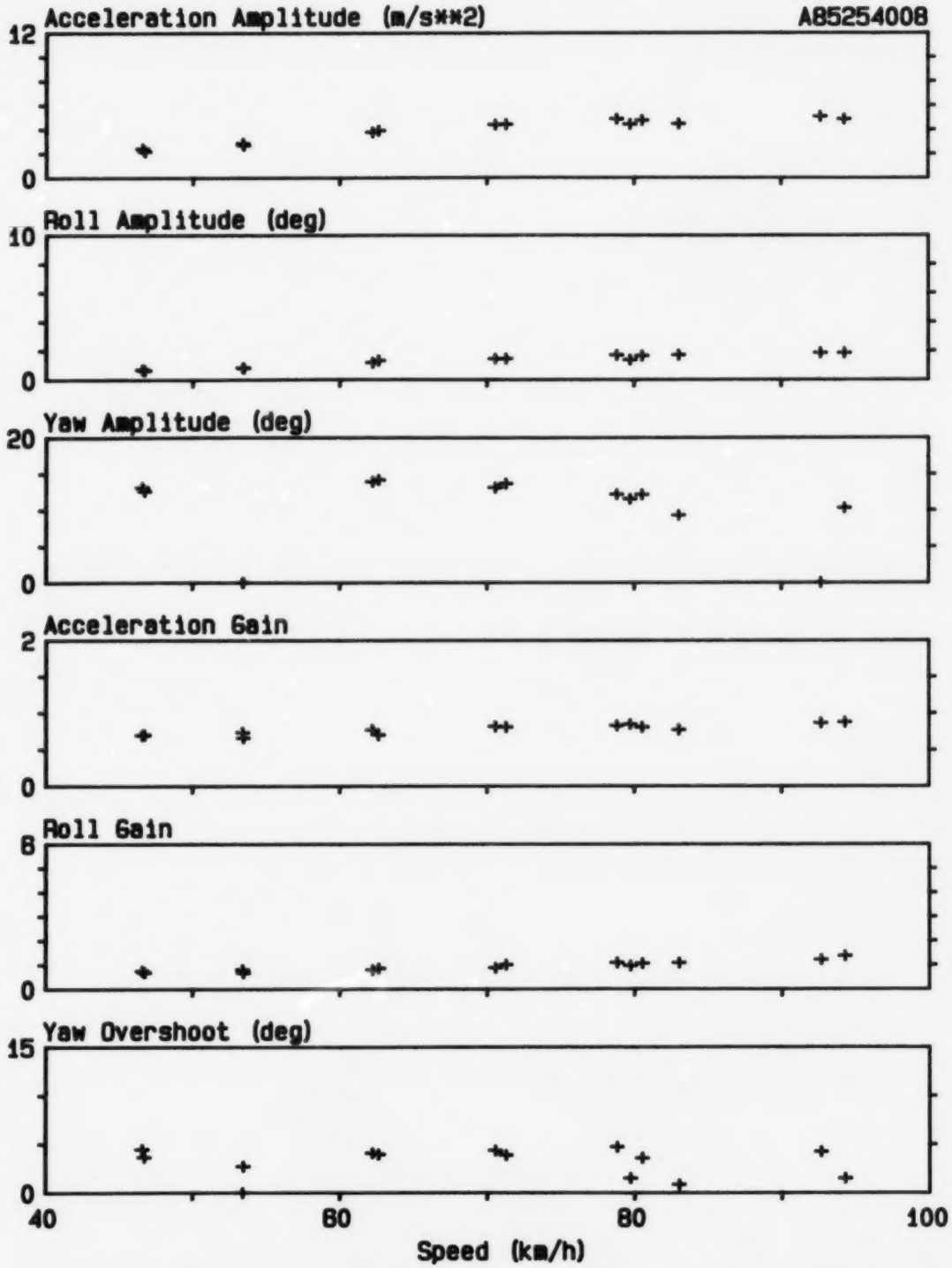


Figure 17/ 5-Axle 48 ft Semi, Lane Change,
Vehicle Responses vs Speed

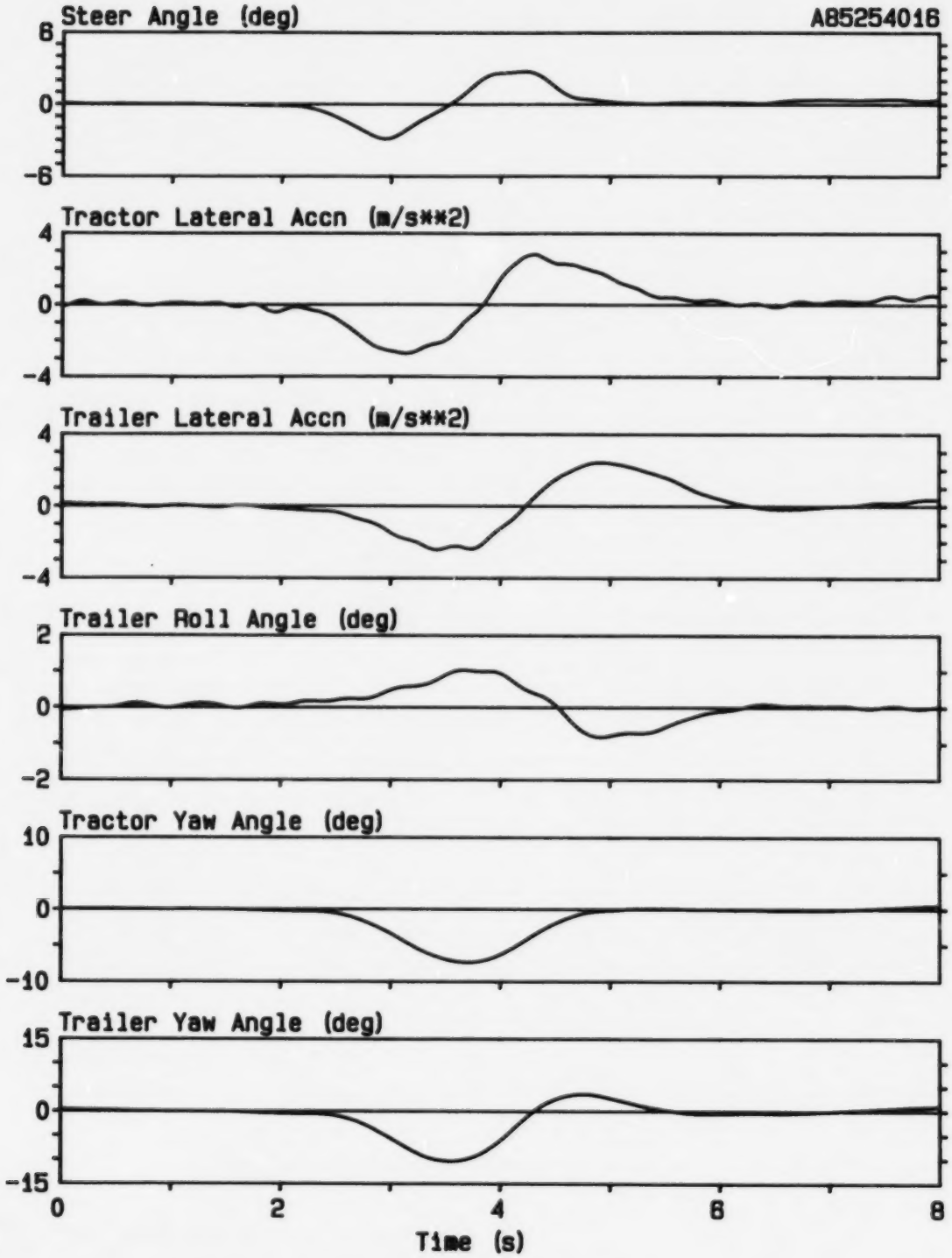


Figure 18/ 5-Axle 48 ft Semi, Lane Change,
Vehicle Responses at 94 km/h

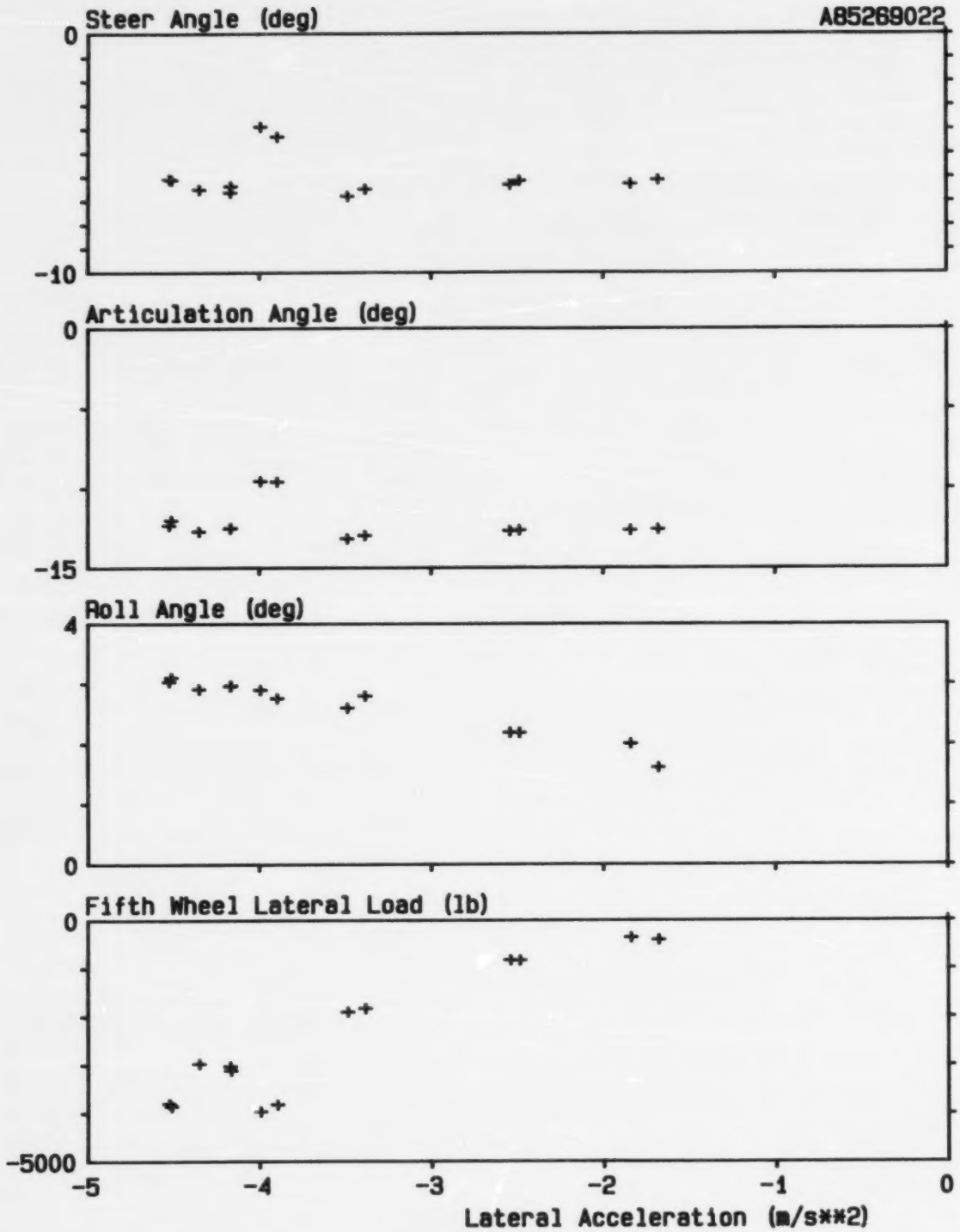


Figure 19/ 5-Axle 48 ft Semi, Steady Circular Turn, Vehicle Responses vs Tractor Lateral Acceleration

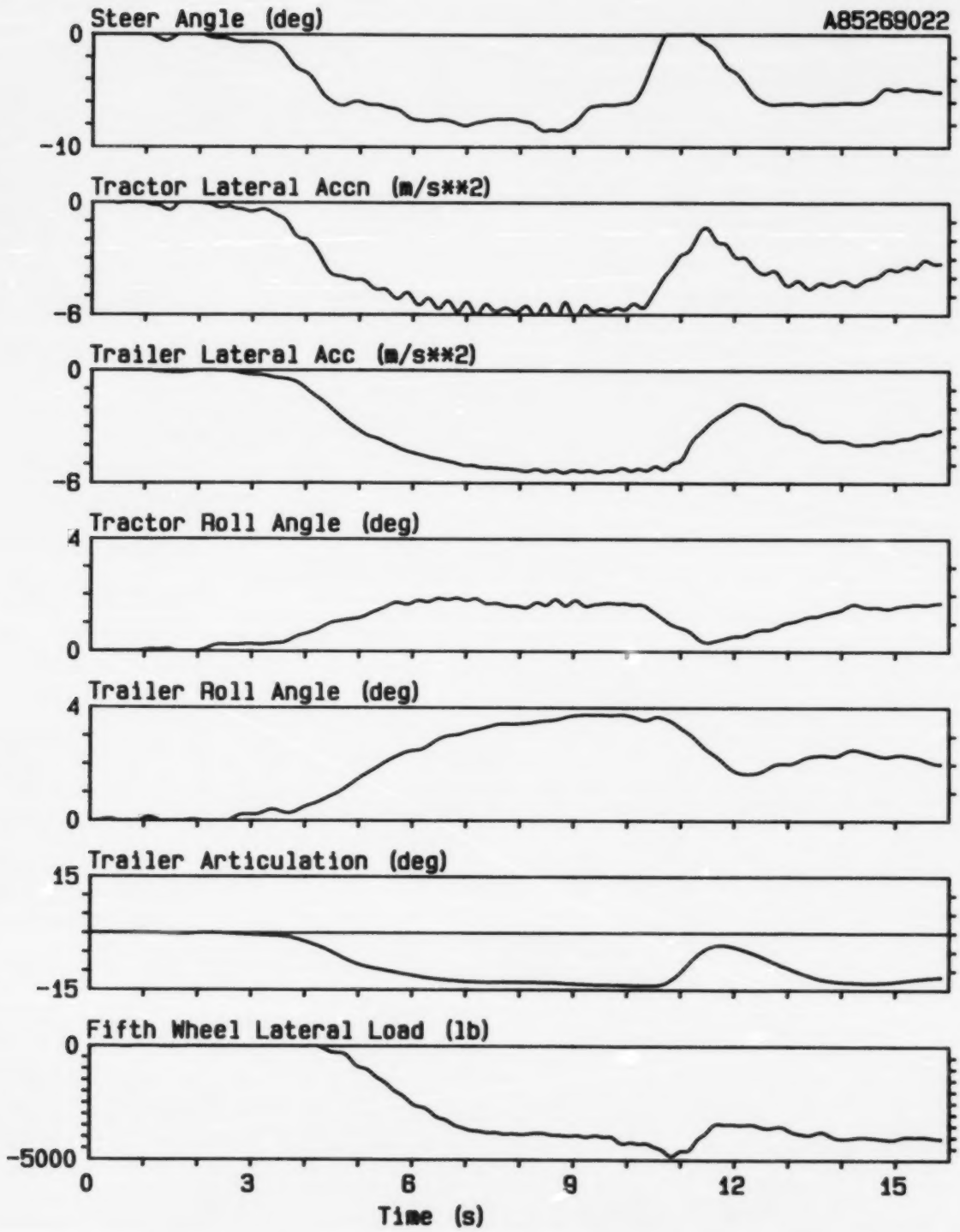


Figure 20/ 5-Axle 48 ft Semi, Steady Circular Turn, Vehicle Responses at 63 km/h

Figure 21/ 5-Axle 48 ft Semi Making Steady Circular Turn

Figure 22/ 5-Axle 48 ft Semi on Tilt Table